ChE 344
Winter 2013
Final Exam + Solution

Thursday, May 2, 2013

Open Course Textbook Only
Closed everything else (i.e., Notes, In-Class Problems and Home Problems

Name_____

Honor Code (Please sign in the space provided below)

"I have neither given nor received unauthorized aid on this examination, nor have I concealed any violations of the Honor Code."

_____
(Signature)

The Basics

1) ____/ 2 pts
2) ____/ 5 pts
3) ____/ 5 pts
4) ____/ 5 pts
5) ____/ 5 pts
6) ____/ 5 pts
7) ____/ 8 pts

Applications

8) ____/10 pts
9) ____/10 pts

Professional

10) ____/20 pts
11) ____/25 pts

Total ____/100 pts

(2 pts) 1) **Chapter 1 Mole Balances**

The reaction

$$A + 2B \rightarrow 2C$$

takes place in a membrane reactor. The feed is only A and B in equimolar proportions. Which of the following set of equations gives the correct mole balances on A, B and C. Species A and B are disappearing and Species C is being formed and C is also diffusing out the sides of a membrane reactor.

Circle the correct answer where <u>all</u> the mole balances are correct

(a)

$$\frac{dF_A}{dV} = r_A$$

$$\frac{dF_B}{dV} = r_B$$ Ans: $-r_C$ is wrong

$$\frac{dF_C}{dV} = -r_C - R_C$$

(b)

$$\frac{dF_A}{dV} = r_A$$

$$\frac{dF_B}{dV} = 2r_B$$ Ans: $-2r_C$ is wrong

$$\frac{dF_C}{dV} = -2r_C - R_C$$

(c)

$$\frac{dF_A}{dV} = r_A$$

$$\frac{dF_B}{dV} = r_B$$ Ans: $2r_C$ is wrong

$$\frac{dF_C}{dV} = 2r_C - R_C$$

(d)

$$\frac{dF_A}{dV} = r_A$$

$$\frac{dF_B}{dV} = 2r_A$$ Ans: correct

$$\frac{dF_C}{dV} = -2r_A - R_C$$

(e) None of the above

Solution

Answer is (d).

(5 pts) 2) Circle the correct answer.
Consider the following Levenspiel plot for a reversible reaction A $\rightleftarrows$ Product

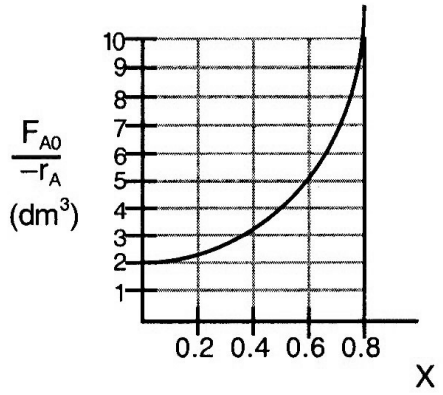


Figure 2-1

(1 pt) (a) The equilibrium conversion X_e in a 3 dm^3 reactor is

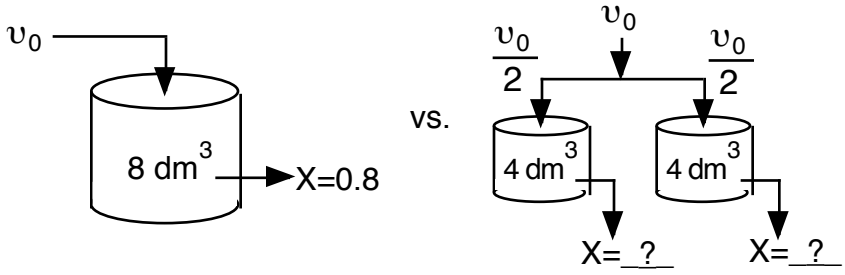
(1) $X_e < 0.6$ (2) $X_e = 0.6$ (3) $X_e > 0.6$ (4) Can't tell from the information given

(1 pt) (b) The flow rate to an 8 dm^3 CSTR corresponding to Figure 2-1 where 80% conversion is achieved is

(1) $F_{A0} = 0.8$ mol/s (2) $F_{A0} = 10$ mol/s

(3) $F_{A0} = 1$ mol/s (4) Can't tell from the information given

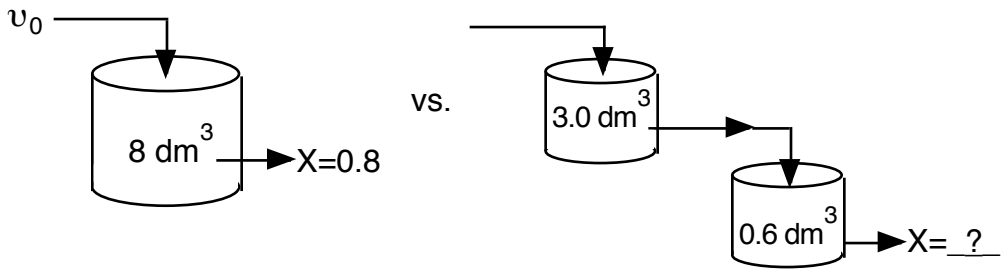
(1 pt) (c) If the conversion achieved in a single 8 dm^3 CSTR is 80%, what would the conversion be if the flow is equally divided into two CSTRs in parallel with each reactor having a volume of 4 dm^3 each (same total volume).



The total reactor volume is constant at 8 dm^3.
The conversion for the two reactors in parallel is

(1) $X > 0.8$ (2) $X < 0.8$ (3) $X = 0.8$ (4) Can't tell from the information given

(2 pts) (d) If the conversion achieved in a single 8 dm^3 CSTR is 80%, what would the conversion be if two CSTRs are connected in series with first reactor having a volume of approximately 3.0 dm^3 and the second reactor having a volume of 0.6 dm^3.



The conversion for the two reactors in series is

(1) X > 0.8 (2) X < 0.8 (3) X = 0.8 (4) Can't tell from the information given

Solution

(a) Ans. (3) $X_e > 0.8$

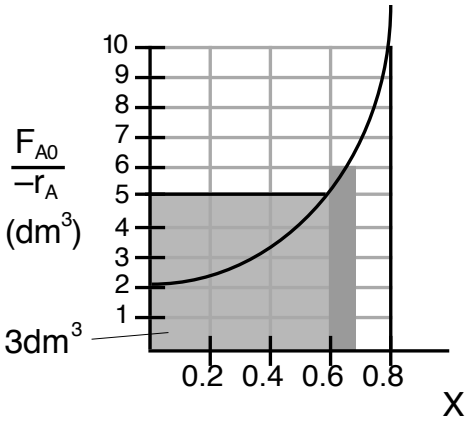
(b) Ans. (d) Can't tell from information given

(c) Ans. (3) X = 0.8. See p161.

(d) Ans. (2) X < 0.8. Try X = 0.6

$3\ dm^3 = 5\ dm^3 \times 0.6 = 3\ dm^3$ checks

Try $\Delta V = 0.1$ between X = 0.6 and 0.7 $V = 0.1 \times 6\ dm^3 = 0.6\ dm^3$ checks



(5 pts) 3) Consider the following reaction for parts (a), (b) and (c)

$$2A + B \underset{\leftarrow}{\overset{\rightarrow}{}} C$$

Write the rate law in terms of the specific reaction rate and species concentration when

(1 pt) (a) The reaction is irreversible and second order in A, and independent of the concentration of C, and overall first order.

$-r_A =$ _____

(1 pt) (b) The reaction is elementary and reversible

$-r_A =$ _____

(1 pt) (c) Now consider the case when the reaction is first order in A and first order in B at high concentrations of A and B and is first order in A and second order in B at low concentrations of B. The rate law is

$-r_A =$ _____

(2 pt) (d) The irreversible reaction is catalyzed on a Pt surface where surface reaction limits and B is not adsorbed on the surface but reacts with adsorbed A on the surface.

$-r_A =$ _____

Solution

$$A + \frac{B}{2} \rightarrow \frac{C}{2}$$

(a) $-r_A = k_A \dfrac{C_A^2}{C_B}$

(b) $-r_A = k_A \left[C_A^2 C_B - \dfrac{C_C}{K_C} \right]$

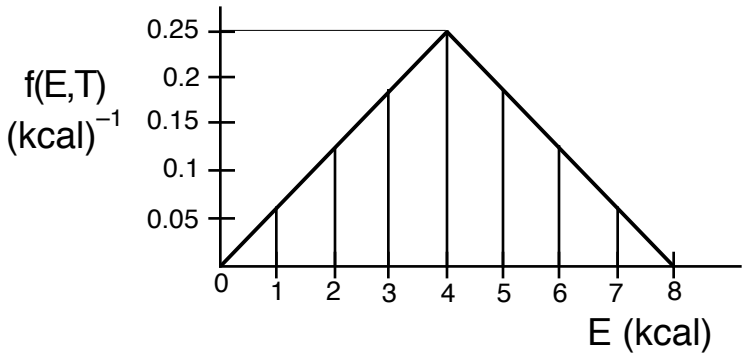
(c) $-r_A = \dfrac{k_1 C_A C_B^2}{1 + k_2 C_B}$

(d) $A + S \underset{\leftarrow}{\overset{\rightarrow}{}} A \bullet S$ $\qquad C_{A\bullet S} = P_A K_A C_V$ $\qquad C_V = \dfrac{C_t}{1 + K_A P_A + K_C P_C}$

$2A \bullet S + B \rightarrow C \bullet S$ $\qquad r_B = k_S C_{A\bullet S}^2 P_B$

$C \bullet S \rightarrow C + S$ $\qquad C_{A\bullet S} = K_C P_C$ $\qquad -r_A = \dfrac{\overbrace{k_S K_A^2}^{k} P_A^2 P_B}{\left(1 + K_A P_A + K_C P_C\right)^2}$

(5 pts) 4) The following figure shows the energy distribution function at 300 K for the reaction $A + B \rightarrow C$



(a) What fraction of the collisions have energies between 3 and 5 kcal?
(b) What fraction of collisions have energies greater than 5 kcal?

Solution

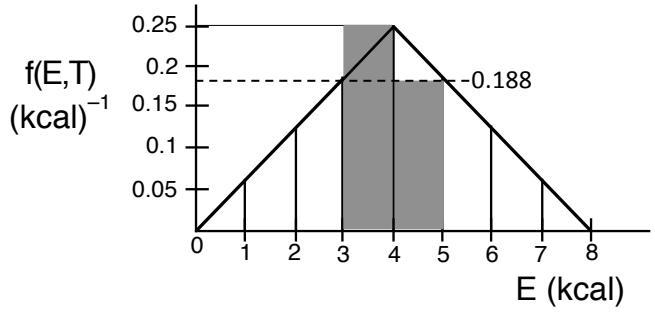
(a) Between 0 and 4 k cal

$$f(E,T) = \left(\frac{0.25}{4}\right)E$$

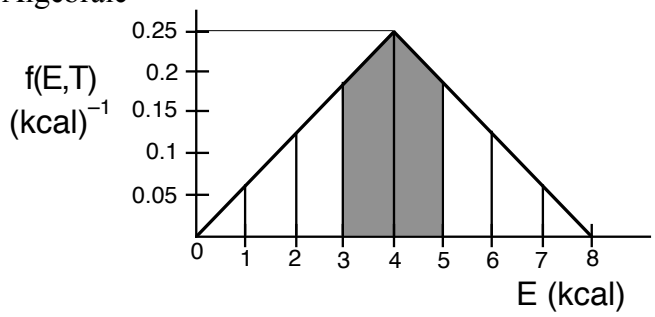
Between 4 and 8 kcal

$$f(E,T) = 0.5 - \frac{0.25C}{4}$$

Graphical (0.25) (1) + 0(0.198)(1) = 0.448, i.e., 45%



Algebraic



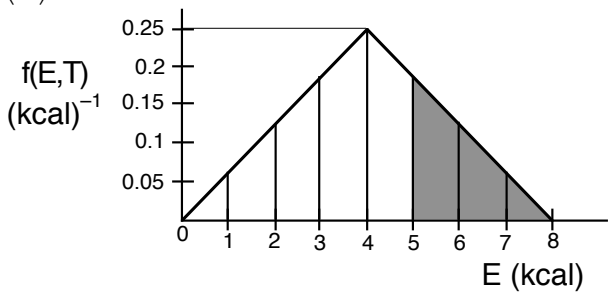
$$\text{at } E = 3 \;\; f(E,T) = \frac{3}{4}.25 = 0.188$$

$$\text{at } E = 5 \;\; f(E,T) = \frac{3}{4}.25 = 0.188$$

$$\text{Area} = 1 \times (0.25) + (1)\frac{3}{4}.25$$

$$= 0.448 = 44.8\%$$

(b) $\left(\frac{3}{4}\right)(.25)$



$$\text{Area} = \left(\frac{3}{4}\right)(.25) \times 3 \times \frac{1}{2} =$$
$$= 0.28 = 28\%$$

(5 pts) 5) For elementary reaction

$$A \rightleftarrows B$$

the equilibrium conversion is 0.8 at 127°C and 0.5 at 227°C. What is the heat of reaction?

ΔH_{Rx} = _____cal/mole A

Solution

$$\frac{X_e}{1-X_e} = K_C$$

At 127°C, $T_1 = 400$ K

$$\frac{0.8}{1-0.8} = 4 = K_C$$

At 227°C, $T_2 = 500$ K

$$\frac{0.5}{0.5} = 1 = K_C$$

$$\ln\frac{K_{C1}}{K_{C2}} = \frac{\Delta H_{Rx}}{R}\left[\frac{1}{T_1} - \frac{1}{T_2}\right] = \frac{\Delta H_{Rx}}{R}\left[\frac{T_2 - T_1}{T_1 T_2}\right]$$

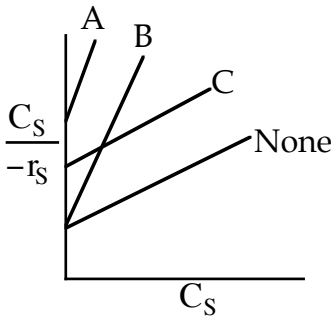
$$\Delta H_{Rx} = \frac{T_1 T_2}{(T_2 - T)} R \ln\frac{K_{C1}}{K_{C2}}$$

$$= \frac{(500)(400)}{500-400} 1.987 \ln\frac{1}{4}$$

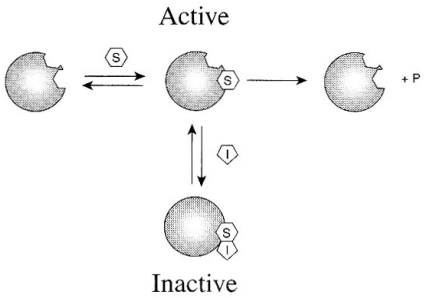
$$= (2{,}000\text{K})1.987\frac{\text{cal}}{\text{molK}}(-1.39)$$

$$= -5{,}509\frac{\text{cal}}{\text{molA}}$$

(5 pts) 6) A **Hanes-Woolf** plot is shown below for the different types of enzyme inhibition. Match the line with the type of inhibition.

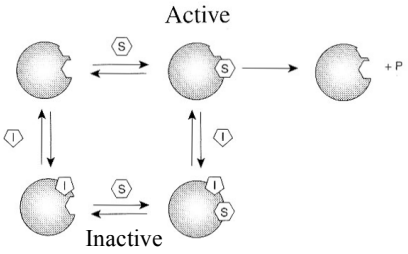


(a) Inhibition Mechanism



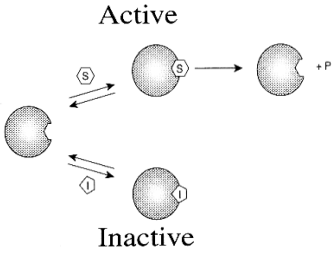
Ans: _____

(b) Inhibition Mechanism



Ans: _____

(c) Inhibition Mechanism



Ans: _____

Solution

(a) B
(b) A
(c) C

(8 pts) 7)

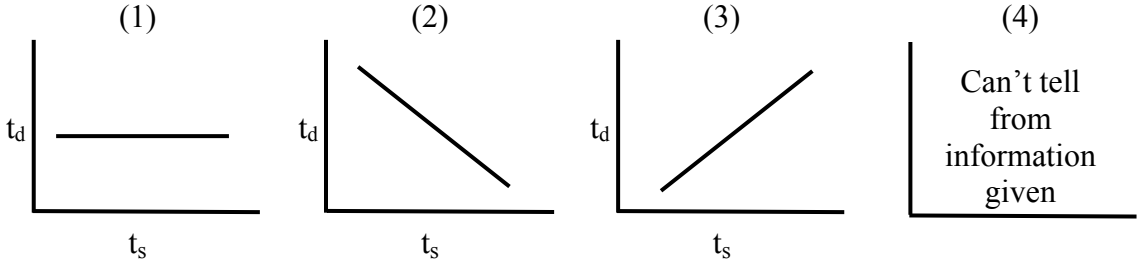
(2pt) (a) Keeping in mind the explosions we discussed this term, suggest at least one possible cause of the West, Texas fertilizer plant explosion on April 15, 2013 that resulted in 14 fatalities.

_____

_____

In the following, circle the correct answer below.

(2 pt) (b) Which of the following figures best represents the relationship between the amount of down time, t_d, and the time the heat exchanger failed after start up, t_s for which the ONCB/ammonia reactor would not explode



(2 pt) (c) Currently 50% conversion is being achieved in an endothermic liquid phase reaction $A + B \rightarrow C + D$ in a CSTR when the reaction is carried out adiabatically and the feed is stoichiometric. If the reaction molar flow rate of B is doubled with everything else held constant, the exit temperature will

Increase Decrease Remain the same Insufficient information to tell

(2 pt) (d) A co-current heat exchanger with a variable ambient temperature will always have a greater equilibrium conversion than a heat exchanger with a constant ambient temperature when an exothermic reversible reaction is taking place.

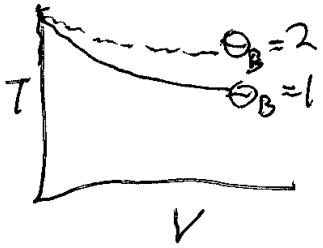
True False Insufficent informtion to tell

Solution

(a) Ans. Heat Exchange Failure or
Ans. Cold feed to the reactor interrupted. Either answer acceptable

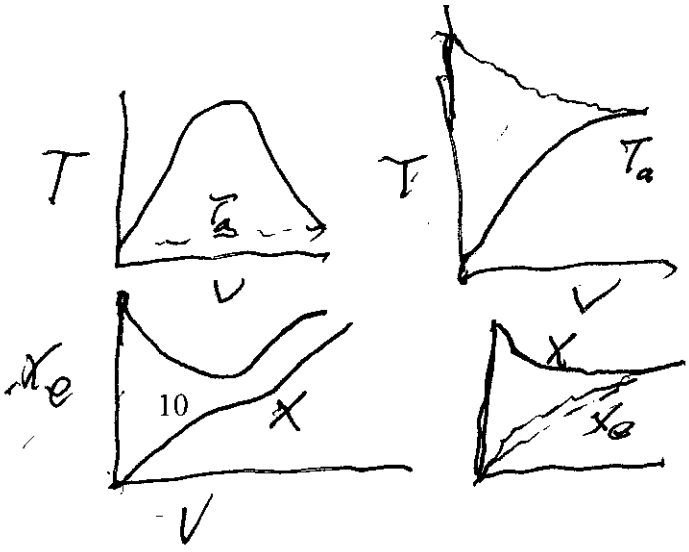
(b) (3) The later the heat exchanger fails. Since the start of the reaction the more reactant will have been conserved. Consequently when the heat exchanger fails at a later time, t_s, the rate will be slower allowing one down time, t_a before $Q_g > Q_R$

(c) Increase



Excess species "B" acts in the same way as an inert does.

(d) False



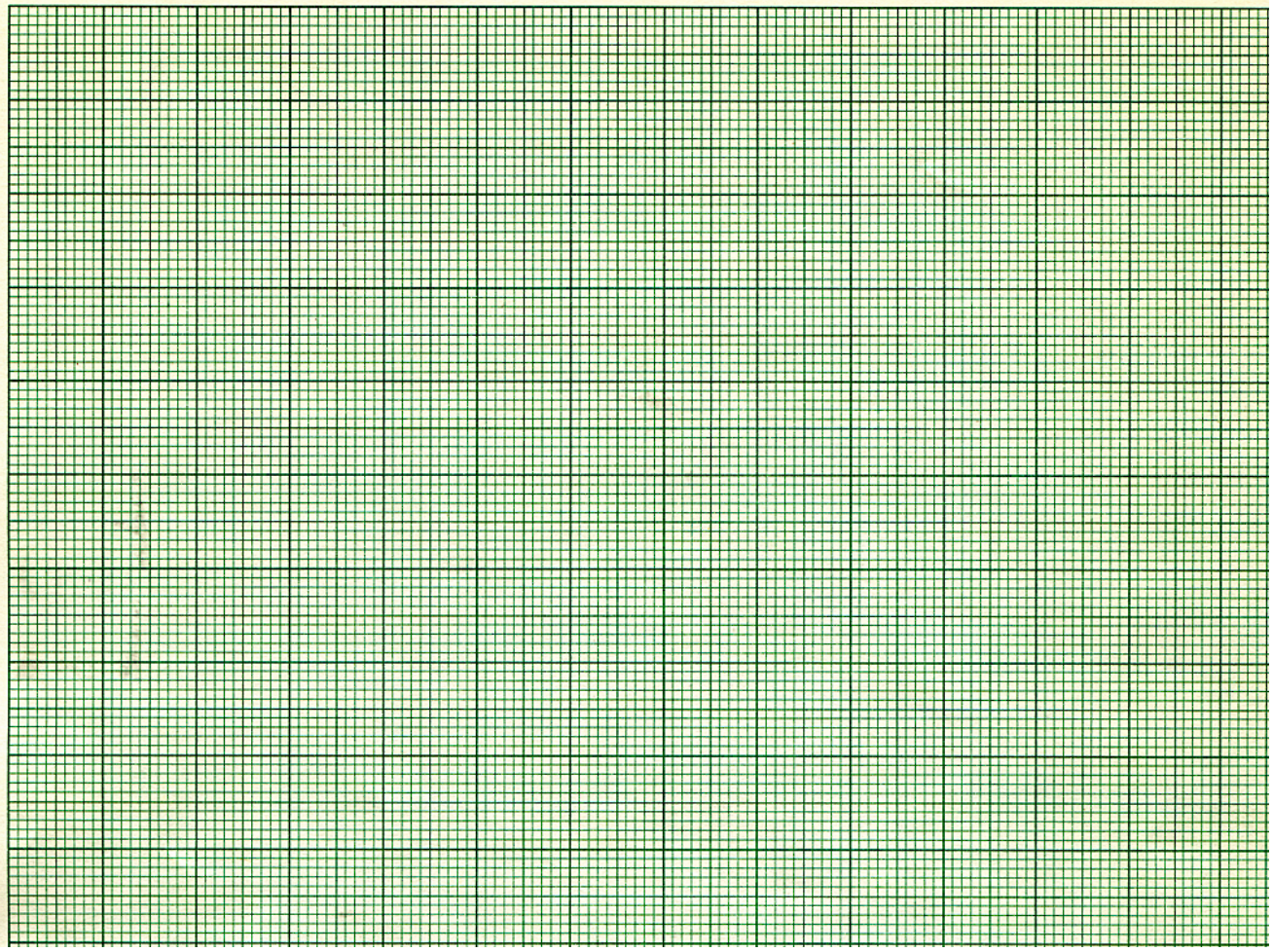
(10 pts) 8) Experimental data for the gas phase catalytic reaction

$$A + B \rightarrow C$$

is shown below. The limiting step in the reaction is known to be irreversible, so that the overall reaction is irreversible. The reaction was carried out in a differential reactor (i.e., virtually no concentration gradient down the reactor) to which A, B, and C were all fed.

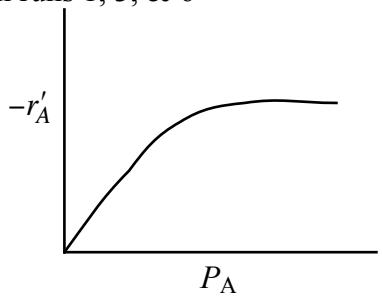
Run Number	P_A (atm)	P_B (atm)	P_C (atm)	Reaction rate (mol)/(gcat • s)
1	1	1	2	0.114
2	1	10	2	1.140
3	10	1	2	0.180
4	1	20	2	2.273
5	1	20	10	0.926
6	20	1	2	0.186
7	0.1	1	2	0.0243

(a) Suggest a rate law consistent with the experimental data. (Hint: Sketch $(-r_A')$ as a function of P_A, as a function of P_B, and as a function of P_C.)
(b) From your rate expression, which species can you conclude are adsorbed on the surface?
(c) Suggest a mechanism that is consistent with the rate law in part (a).



Solution

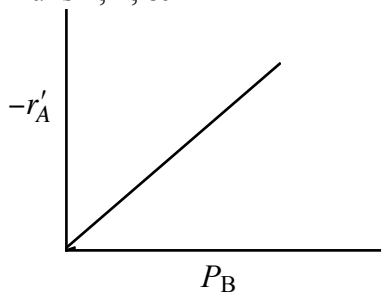
From runs 1, 3, & 6



← Suggests P_A is in both numerator and denominator of the rate law

$$-r'_A \sim \frac{(P_A)(\ ?\ )}{1 + K_A\ P_A + (\ ?\ )} \qquad \text{(A)}$$

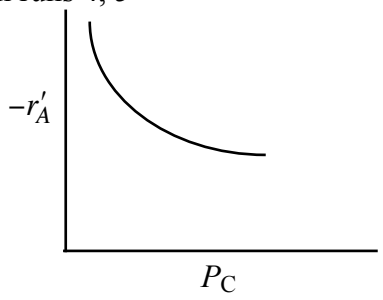
From runs 1, 2, & 4



← Suggests P_B is only in the numerator of the rate law

$$-r'_A \sim P_B \qquad \text{(B)}$$

From runs 4, 5



← Suggests P_C is in the denominator of the rate law

$$-r'_A \sim \frac{1}{1 + K_C\ P_C + \ldots} \qquad \text{(C)}$$

Combining Equations (A), (B) and (C) above

(a) $$-r'_A = \frac{k\ P_A\ P_B}{1 + K_A\ P_A + K_C\ P_C}$$

(b) A and C are on the surface

$$\mathrm{A + S} \rightleftarrows \mathrm{AS}$$

(c) $$\mathrm{A \bullet S + B \rightarrow C \bullet S}$$

$$\mathrm{C \bullet S} \rightleftarrows \mathrm{C + S}$$

(10 pts) 9) The reversible liquid phase reaction

$$A \underset{\leftarrow}{\overset{\rightarrow}{}} B$$

is carried out in a 12 dm^3 CSTR with heat exchange. Both the entering temperature, T_0, and the heat exchange fluid, T_a, are at 330 K. An equal molar mixture of inerts and A enter the reactor.

(6 pt) (a) What product of the heat transfer coefficient and heat exchange area would give the maximum conversion?

Ans: UA = _____ cal/h/K

(4 pt) (b) Using UA from part (a), what is the maximum conversion that can be achieved in this reactor?

Ans: X_{max} = _____

Additional Information

The G(T) curve for this reaction is shown below

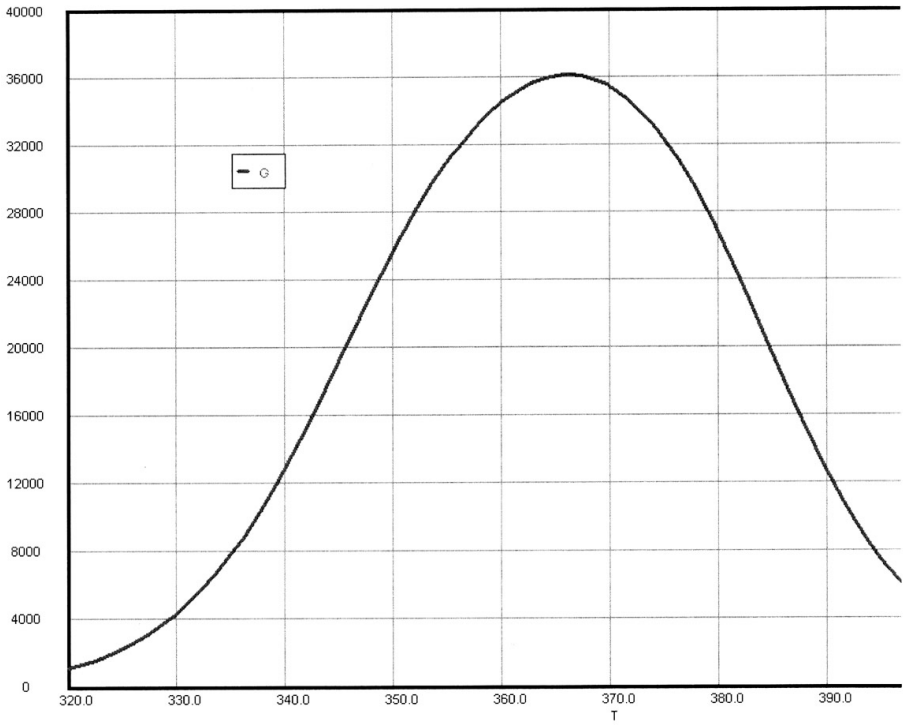
$C_{P_A} = C_{P_B} = 100 \text{ cal/mol/K}$, $C_{P_I} = 150 \text{ cal/mol/K}$

$F_{A0} = 10 \text{ mol/h}$, $C_{A0} = 1 \text{ mol/dm}^3$, $\upsilon_0 = 10 \text{ dm}^3\text{/h}$

$\Delta H_{Rx} = -42{,}000 \text{ cal/mol}$

$k = 0.001 \text{ h}^{-1}$ at 300K with $E = 30{,}000 \text{ cal/mol}$

$K_C = 5{,}000{,}000$ at 300K



Solution

a) $T_C = T_a = T_0$

$$R(t) = C_{P_0}(1+\kappa)(T - T_C)$$

$$\text{Slope} = C_{P_0}(1+\kappa), \quad \text{Slope} = \frac{36{,}000\,\frac{\text{cal}}{\text{mol}}}{(366)-(330)\text{K}} = \frac{36{,}000}{36}\,\frac{\text{cal}}{\text{mol K}}$$

$$= 1{,}000\,\frac{\text{cal}}{\text{mol K}} = 250\,\frac{\text{cal}}{\text{mol K}}(1+\kappa)$$

$$\kappa = 3$$

$$C_{P_0} = C_{P_A} + C_{P_I} = 250$$

$$UA = (3)\left(10\,\frac{\text{mol}}{\text{h}}\right)\left(250\,\frac{\text{cal}}{\text{molK}}\right)$$

$$= 7{,}500\,\frac{\text{cal}}{\text{hK}}$$

Ans: UA = __7,500__ cal/h/K

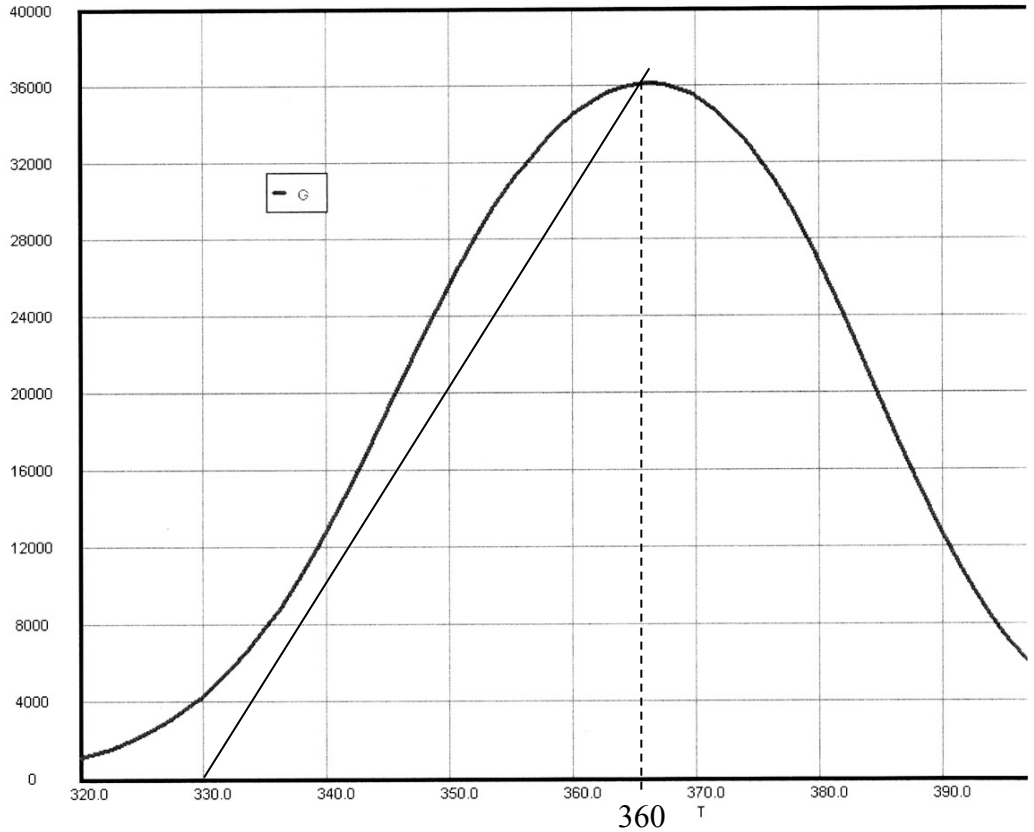
b) $X_{max} = \dfrac{G}{-\Delta H_{Rx}} = \dfrac{36{,}000}{42{,}000} = 0.86$

Ans: X_{max} = __0.86__

ODE Report (RKF45)

Differential equations as entered by the user
[1] d(T)/d(t) = 1

Explicit equations as entered by the user
[1] tau = 1.2
[2] Cpo = 120
[3] DHrx = -42000
[4] E = 30000
[5] k = 0.001*exp((E/1.987)*(1/300-1/T))
[6] Kc = 5000000*exp((DHrx/1.987)*(1 /300-1/T))
[7] Tc = 320
[8] kappa = 6
[9] R = Cpo*(1+kappa)*(T-Tc)
[10] X = tau*k/(1+tau*k+tau*k/Kc)
[11] G = X*(-DHrx)

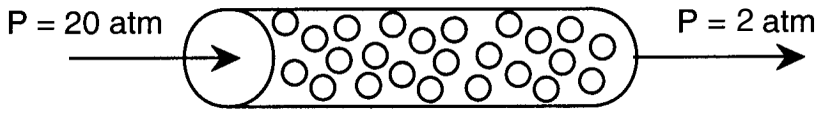

40000
36000
32000
28000
24000
20000
16000
12000
8000
4000
0
G
320.0
330.0
340.0
350.0
360.0
370.0
380.0
390.0
T

360

(20 pts) 10) The irreversible elementary gas phase reaction

$$A + B \longrightarrow C + D$$

is carried out isothermally at 305 K in a packed bed reactor with 100 kg of catalyst.



The entering pressure was 20 atm and the exit pressure is 2 atm. The feed is equal molar in A and B and the flow is in the turbulent flow regime, with F_{A0} = 10 mol/min and C_{A0} = 0.4 mol/dm^3. Currently 80% conversion is achieved. What would be the conversion if the catalyst particle size were doubled and everything else remained the same.?

X = _____

Solution

(a)
$$C_{A0} = y_{A0}\frac{P_{AT_0}}{RT_0} = (0.5)\frac{(20)}{(0.082)(305)} = \frac{10}{(305)(0.082)}$$

$$\boxed{C_{A0} = 0.4\,\text{mol/dm}^3}$$

(b)
$$\frac{dX}{dW} = \frac{-r'_A}{F_{A0}} = \frac{kC_{A0}^2(1-X)^2 y^2}{F_{A0}} = \frac{kC_{A0}^2(1-X)^2(1-\alpha W)}{F_{A0}}$$

$$\frac{X}{1-X} = \frac{kC_{A0}^2}{F_{A0}}\left[W - \frac{\alpha W^2}{2}\right]$$

$$y = \frac{2}{20} = 0.1$$

$$y^2 = (1-\alpha W)$$

$$\alpha = \frac{1-y^2}{W} = \frac{1-0.01}{100} = \frac{0.99}{100}$$

$$\boxed{\alpha = 9.9\times10^{-3}\,\text{kg}^{-1}}$$

$$\frac{0.8}{1-0.8} = \frac{k\left[0.4\frac{\text{mol}}{\text{dm}^3}\right]^2}{10\frac{\text{mol}}{\text{min}}}\left[100 - \frac{\left(9.9\times10^{-3}\times10^4\right)}{2}\text{kg}\right]$$

$$4 = k[0.16][100-49.5]/10$$

$$k = 4.95\frac{\text{dm}^6}{\text{kg mol min}}$$

$$\boxed{k = \frac{(9 \cdot 10)}{(50.5)(0.059)} = 30.2 \frac{dm^3}{mol\ \ min}}$$

For the turbulent flow

$$\alpha \sim \frac{1}{D_P}$$

$$\alpha_2 = \alpha_1 \frac{D_{P1}}{D_{P2}} = \frac{\alpha_1}{2} = \frac{9.9 \times 10^{-3} kg^{-1}}{2} = 4.95 \times 10^{-3}\ kg^{-1}$$

$$\frac{X}{1-X} = \frac{\left(4.95 \frac{dm^6}{kg\ mol\ min}\right)\left(0.4 \frac{mol}{dm^3}\right)^2}{10 \frac{mol}{min}} \left[100 - \frac{4.95 \times 10^{-3} (100)^2}{2} kg\right]$$

$$= 0.08[100 - 24.7] = 5.95$$

$$X = \frac{5.95}{6.95} = 0.86$$

(25 pts) 11) The following reactions are taking place in a 2,000 dm^3 liquid phase batch reactor under a pressure of 400 psig

$$A + 2B \xrightarrow{k_{1A}} C \qquad \Delta H_{Rx1B} = -5{,}000 \text{ cal/mol} \qquad -r_{1A} = k_{1A} C_A C_B^2$$

$$3C + 2A \xrightarrow{k_{2A}} D \qquad \Delta H_{Rx2C} = +10{,}000 \text{ cal/mol} \qquad -r_{2A} = k_{2A} C_A C_C$$

$$B + 3C \xrightarrow{k_{3C}} E \qquad \Delta H_{Rx3B} = -50{,}000 \text{ cal/mol} \qquad -r_{3C} = k_{3C} C_B C_C$$

The initial temperature is 450 K and the initial concentrations of A, B and C are 1.0, 0.5 and 0.2 mol/dm^3 respectively. The coolant flow rate was at its maximum value so that $T_{a1} = T_{a2} = T_a = 400$ K so that the product the exchange area and overall heat transfer coefficient, UA, is UA = 100 cal/s•K.

(2 pt) (a) If $Q_r > Q_g$ at time t = 0, and there is no failure of the heat exchange system, is there any possibility that reactor will run away? Explain_____

_____

_____

_____

(4 pt) (b) What is Q_r at t = 0?

(10 pt) (c) What is Q_g at t = 0?

(3 pt) (d) What is the initial rate of increase in temperature, (dT/dt) at t = 0?

$$\frac{dT}{dt} = \_\_\_\_\_$$

(3 pt) (e) Suppose that the ambient temperature T_a is lowered from 400 K to 350 K, what is the initial rate of reactor temperature change?

$$\frac{dT}{dt} = \_\_\_\_\_$$

(3 pt) (f) A suggestion was made to add 50 moles of inerts at a temperature of 450 K. Will the addition of the inerts make runaway more likely or less likely? How? Show quantitatively.

Additional information

As a first approximation, assume all heats of reaction are constant (i.e., $\Delta C_{P_{ij}} \cong 0$)

Specific reaction rates at 450 K are

$$k_{1A} = 1 \times 10^{-3} \left(dm^3/mol\right)^2/s$$

$$k_{2A} = \frac{1}{3} \times 10^{-3} \left(dm^3/mol\right)^2/s$$

$$k_{3C} = 0.6 \times 10^{-3} \left(dm^3/mol\right)^2/s$$

$$C_{P_A} = 10 \text{ cal/mol/K} \qquad C_{P_D} = 80 \text{ cal/mol/K}$$

$$C_{P_B} = 10 \text{ cal/mol/K} \qquad C_{P_E} = 50 \text{ cal/mol/K}$$

$$C_{P_C} = 50 \text{ cal/mol/K}$$

Solution

Part (a)

$$\frac{dT}{dt} = \frac{Q_g - Q_r}{N_A C_{P_A} + N_B C_{P_B} + N_C C_{P_C}}$$

If $Q_r > Q_g$ then the temperature can only decrease causing the specific reaction rates k_i to decrease, hence runaway is unlikely.

Part (b)

$$Q_r = UA\left(T - T_a\right) = 100\frac{cal}{s \bullet K}\left[450 - 400\right]K = 5{,}000\frac{cal}{s}$$

Part (c)

$$Q_g = V\left[r_{1B}\Delta H_{Rx1B} + r_{2C}\Delta H_{Rx2C} + r_{3B}\Delta H_{Rx3B}\right]$$

Initially T = 350 K

$$\text{Reaction 1:} \quad \frac{r_{1A}}{-1} = \frac{r_{1B}}{-2} = \frac{r_{1C}}{1} \qquad r_{1B} = 2r_{1A}$$

$$\text{Reaction 2:} \quad \frac{r_{2A}}{-2} = \frac{r_{2C}}{-3} = \frac{r_{2D}}{1} \qquad r_{2C} = \frac{3}{2}r_{2A}$$

$$\text{Reaction 3:} \quad \frac{r_{3B}}{-1} = \frac{r_{3C}}{-3} = \frac{r_{3E}}{1} \qquad -r_{3B} = \frac{1}{3}r_{3C}$$

$$Q_g = V\left[2k_{1A}C_A C_B^2\right]\left[-\Delta H_{Rx1B}\right] + V\left[\frac{3}{2}k_{2A}C_A C_C\right]\left[-\Delta H_{Rx2C}\right] + V\left[\frac{1}{3}k_{3C}C_B C_C\right]\left[-\Delta H_{Rx3C}\right]$$

$$= (2{,}000)\underbrace{\left[(2)\left(10^{-3}\right)(1)(0.5)^2 5{,}000\right]}_{5{,}000} + 2{,}000\left[\underbrace{\frac{3}{2}\left(\frac{1}{3}\times 10^{-3}\right)(1)(0.2)[10{,}000]}_{-2{,}000}\right] +$$

$$+2{,}000\underbrace{\left[\frac{1}{3}\left(0.6\times 10^{-3}\right)(0.5)(0.2)\right]\bullet[50{,}000]}_{+2{,}000} = 5{,}000$$

$$Q_g = 5{,}000\,cal/s$$

$$\frac{dT}{dt} = \frac{Q_r - Q_g}{N_{A0}C_{P_A} + N_{B0}C_{P_B} + N_{C0}C_{P_C}} = \frac{5{,}000 - 5{,}000}{N_{A0}C_{P_A} + N_{B0}C_{P_B} + N_{C0}C_{P_C}} = 0$$

Part (d)

$$N_{A0}C_{P_A} = C_{A0}VC_{P_A} = (1)(2{,}000)(10) = 20{,}000$$

$$N_{B0}C_{P_B} = C_{B0}VC_{P_B} = (0.5)(2{,}000)(10) = 10{,}000$$

$$N_{C0}C_{P_C} = C_{C0}VC_{P_C} = (0.2)(2{,}000)(50) = 20{,}000$$

$$\frac{dT}{dt} = \frac{Q_g - Q_r}{50{,}000} = \frac{5{,}000 - 5{,}000}{50{,}000} = 0$$

Part (e)

Drop T_a by 50

$$Q_r = UA(T - T_a) = 100(450 - 350) = 10{,}000$$

$$\frac{dT}{dt} = \frac{5{,}000 - 10{,}000}{50{,}000} = -0.1$$

Part (f)

$$\frac{dT}{dt} = \frac{Q_g - Q_r}{\sum N_i C_{P_i}} = \frac{\left[r_{1B} V \Delta H_{Rx1B} + r_{2C} V \Delta H_{Rx2C} + r_{3A} V \Delta H_{Rx3A}\right] - UA(T - T_a)}{N_A C_{P_A} + N_B C_{P_B} + N_C C_{P_C} + N_D C_{P_D} + N_E C_{P_E} + N_{Inerts} C_{P_{Inerts}}}$$

Inerts (N_{Inerts}) will not change Q_g or Q_r, they will only slow the rate of temperature increase or decrease.